DigitalGlobe Use of EESS Frequency Allocations

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Senior RF/Ground System Engineer

QuickBird Usage of 8025-8400 MHz

- Wideband Downlink
  - 320 Mbps transmitted using OQPSK, center frequency 8185 MHz, single polarization (RHCP carrier), operated down to 5 deg elevation
  - Baseline Remote Ground Terminal (RGT): 7.3 m diameter reflector antenna
  - With Reed-Solomon coding, uncorrectable bit errors due to thermal noise are non-existent
  - Upgraded RGT design for WV (5.4 m diameter reflector antenna) will support QB, but with less link margin
  - Three locations: Tromsø, Norway; Fairbanks, AK, USA; Wilkes-Barre, PA, USA (receive only)
- Narrowband Downlink
  - 16 kbps real-time, 256 kbps playback H&S data, SGLS waveform, center frequency 8030 MHz, single polarization (RHCP), operated down to 5 deg elevation
  - Minimal degradation to wideband performance

WorldView Usage of 8025-8400 MHz

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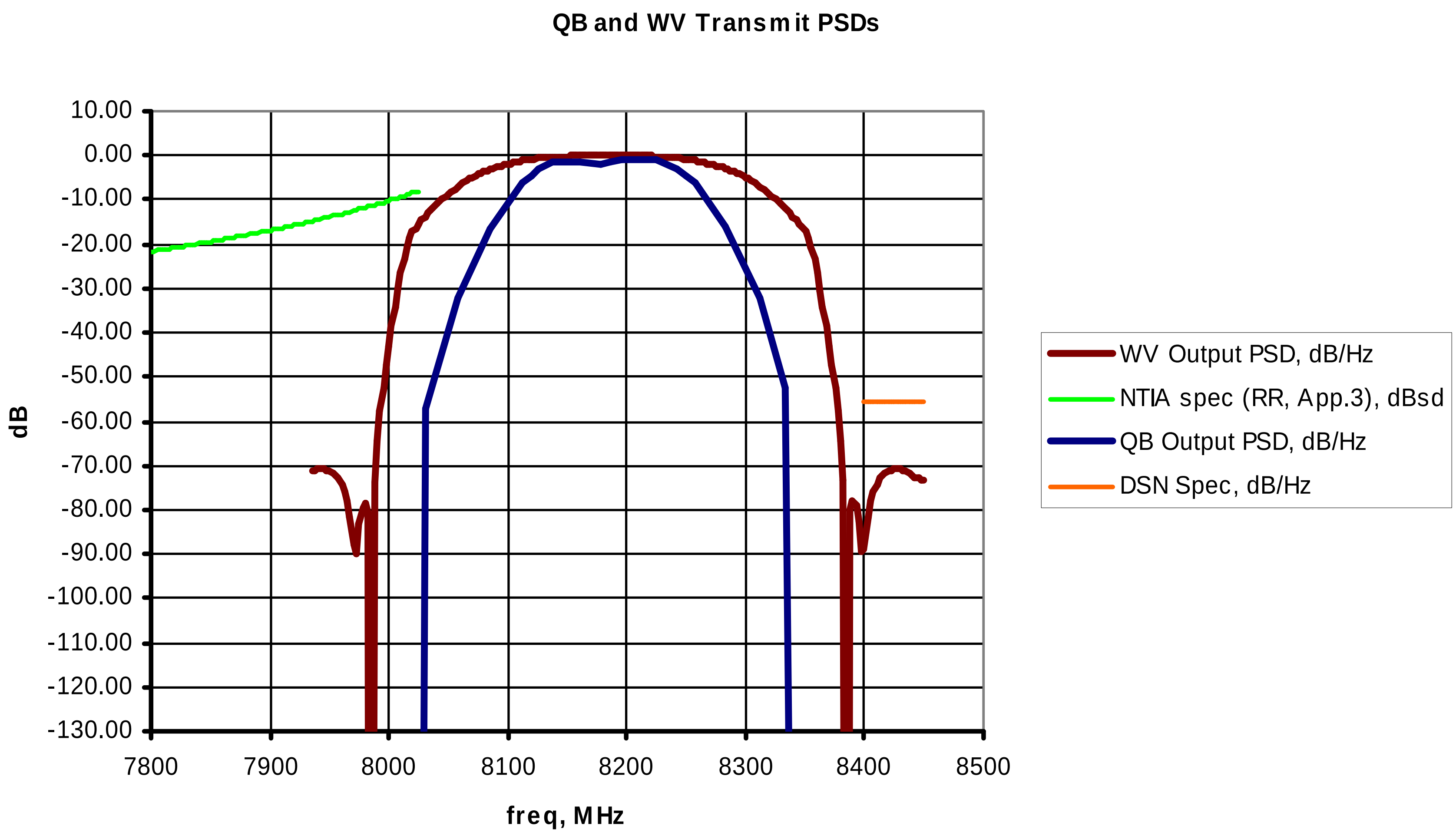
- Wideband Downlink
  - 800 Mbps transmitted using OQPSK, center frequency 8185 MHz, dual polarization (RHCP & LHCP carriers), operated down to 5 deg elevation
  - Baseline Remote Ground Terminal (RGT): 5.4 m diameter reflector antenna
  - With Reed-Solomon coding, uncorrectable bit errors due to thermal noise are non-existent
  - Two RGT locations: Norway; Alaska, USA
  - Present 7.3 m antennas at Tromsø and Fairbanks to be upgraded for dual polarization
- Narrowband Downlink
  - 16 kbps real-time, 512 kbps playback H&S data, UAQPSK, center frequency 8380 MHz, single polarization (LHCP), operated down to 5 deg elevation
  - Minimal degradation to wideband performance

WV and QB Maximize Utility of EESS X-Band Allocation



GEO Dual Polarization Technology Adapted By DG for LEO Use

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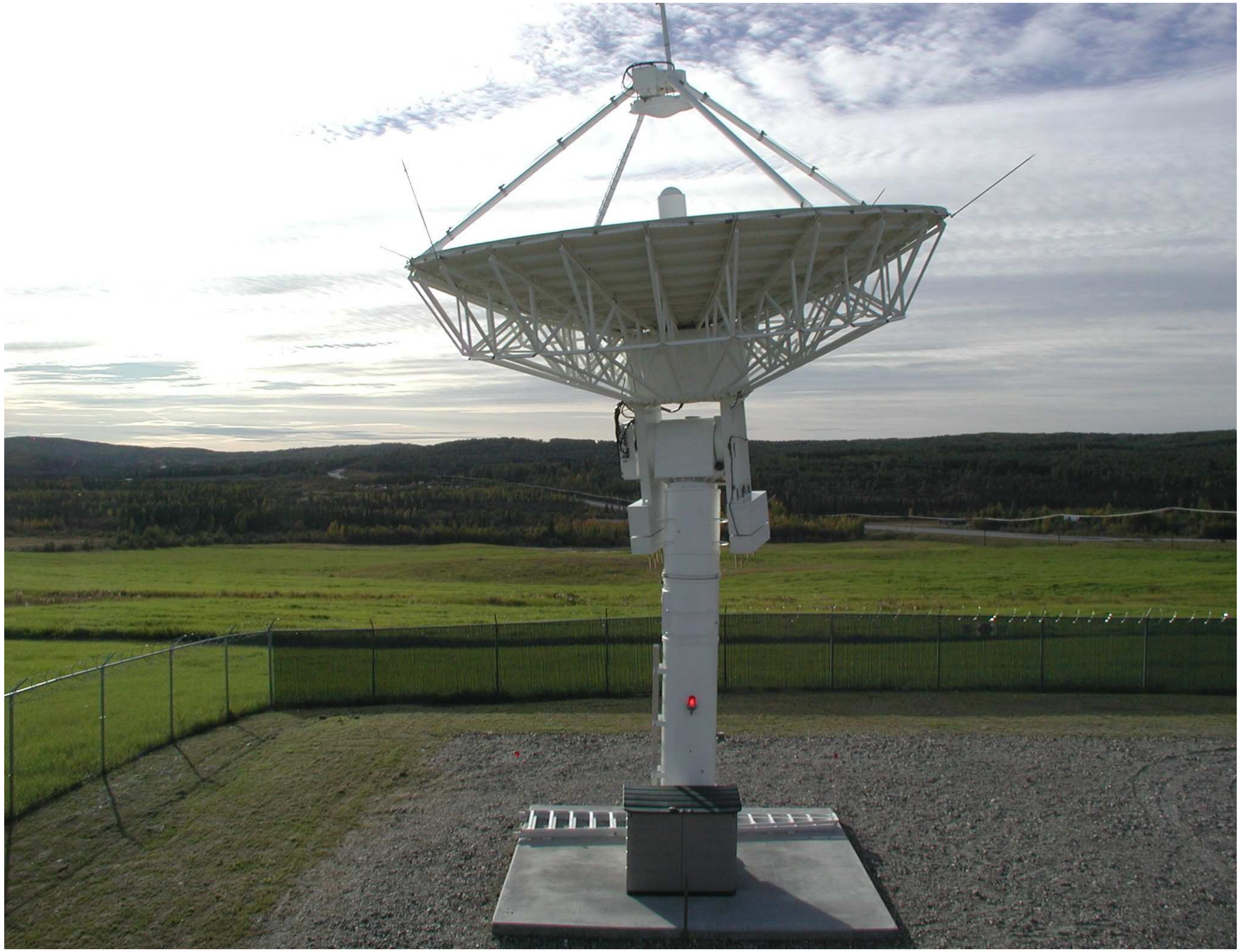
- DG polarization diversity for the WorldView wideband downlink more than doubles the throughput of QB, while using the same allocated bandwidth
- Geosynchronous satellite systems have been using polarization diversity for years
- Pointing requirement for tracking LEO satellite (relative motion) is more stressing case than for GEO
- Improved polarizer and feed horn technology provide low axial ratio over expected auto-tracking pointing error beamwidth
- Cross-polarized interference requirements are met with WV antenna system design

ViaSat 5.4m RGT Antenna

Titan 7.3m Antenna at Fairbanks, AK



Radome at Wilkes-Barre, PA, USA

Equipment Racks at Wilkes-Barre

Simulation and Analysis of Potential Interference Issues

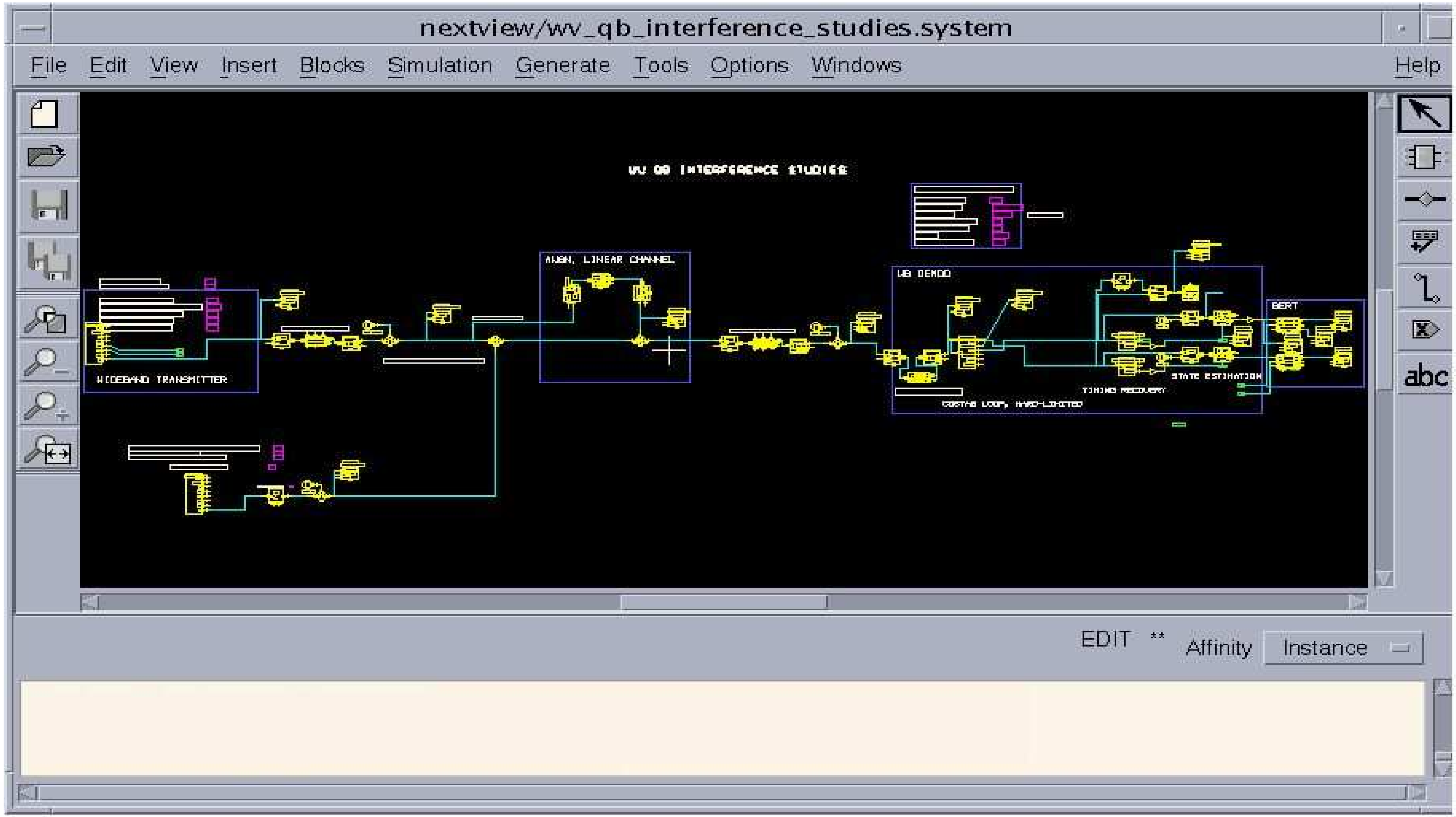
- Interference that causes uncorrectable bit errors results in lost imagery => increases cost of meeting customer requirements
- Simulation of interference scenarios assists in new-mission interference assessment
  - STK, custom software: study geometry, scan-on-scan probabilities
  - SPW: study effect of known interferer (power density, carrier frequency, modulation rate) on DG operations
    - Interfering transmitter signal added to validated QB/WV signal models, added with noise, and demodulated by validated model of receiver
    - Eb/No degradation assessed
  - Link analysis: can compute C/I, C/(N+I) for scenario when I is white over the desired signal passband; this yields a pessimistic view of interference effect when interference is another phase-modulated signal*
    - Alternate methods and/or simulation can give more precise result
- Results of study compared to ITU recommendations, if available for scenario

*"PSK Error Performance With Gaussian Noise and Interference," Arnold S. Rosenbaum, Bell System Technical Journal, Feb., 1969

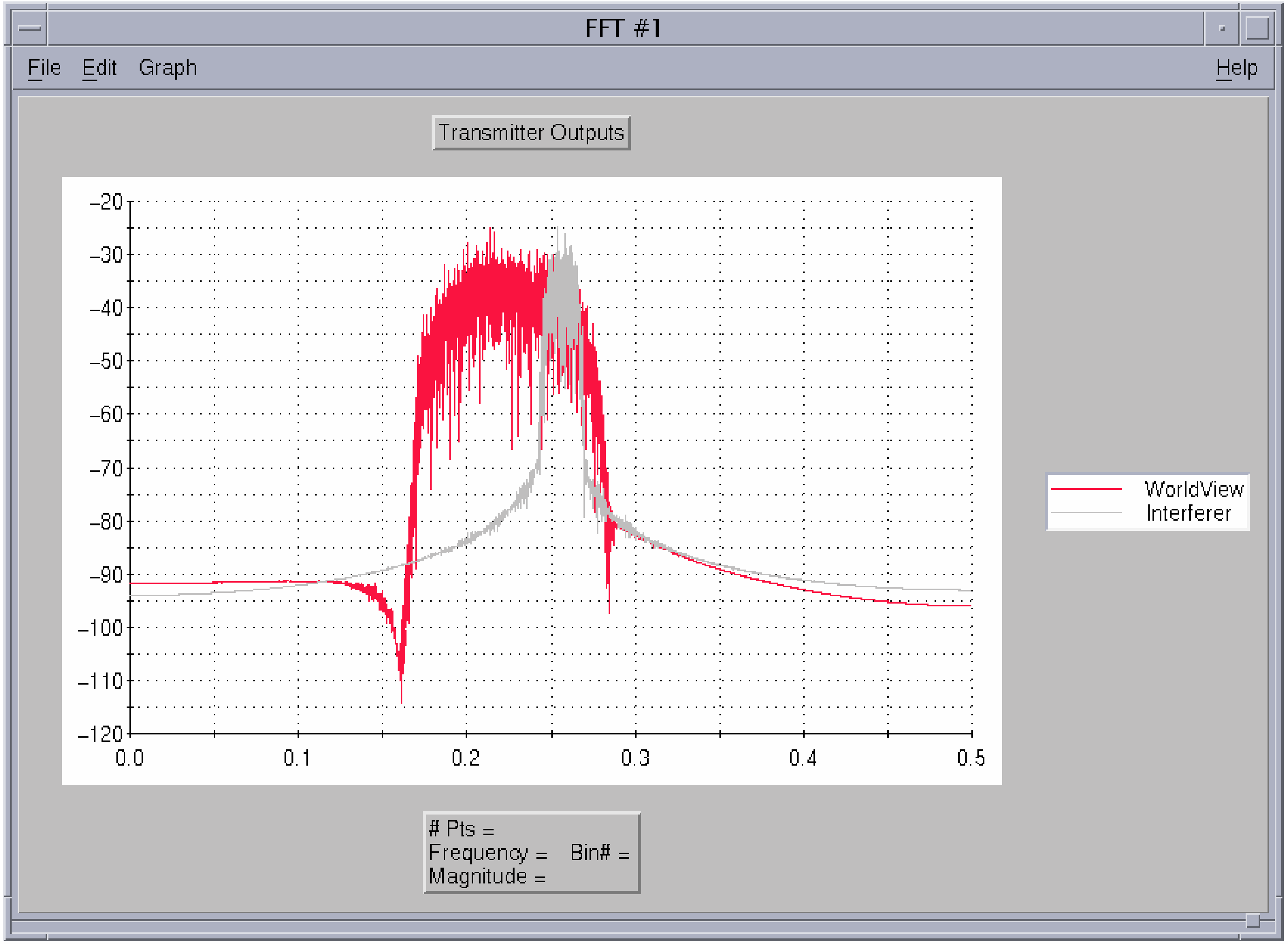
Example: WV With Hypothetical Interferer in F.O.V.

- Interferer wideband downlink characteristics:
  - 8235 MHz center frequency, occupies 8185 to 8285 MHz
  - 100 Mbps OQPSK
  - PFSD equal to WV
- Desire to examine WV WB BER in presence of interference
- Effect to WV NB signal at 8380 MHz also a concern
- Additional issue: autotrack capture of interfering satellite by RGT

DG's SPW Simulation of Wideband Downlink Aids in System Design and Interference Assessment

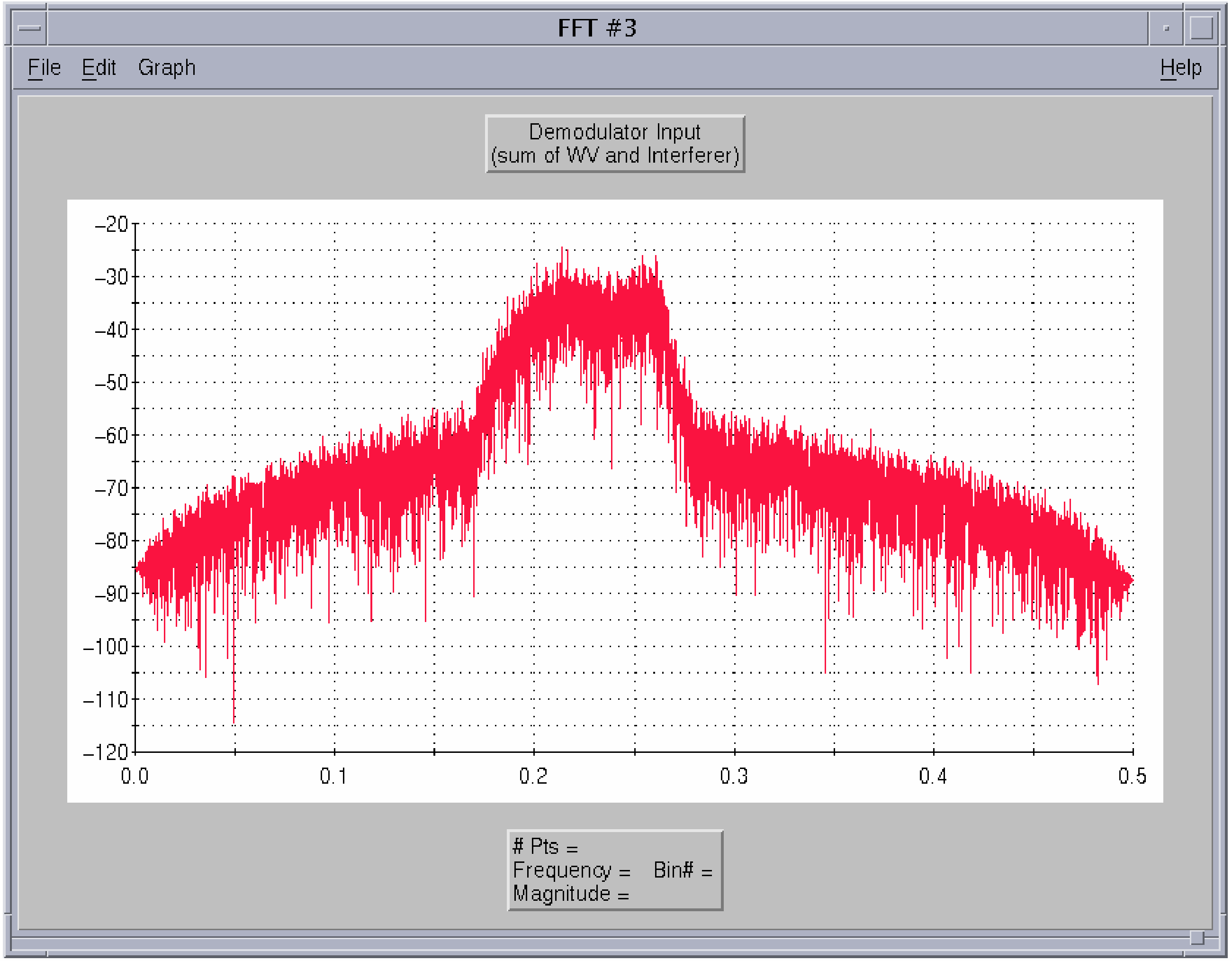


WV and Interferer Transmitter Outputs



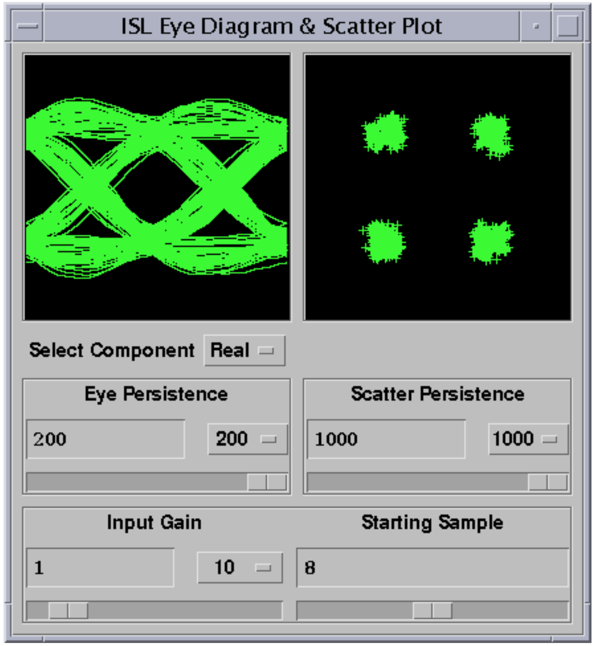
Transmitter output signals shown

Composite Signal P.S.D. at WV Demod Input

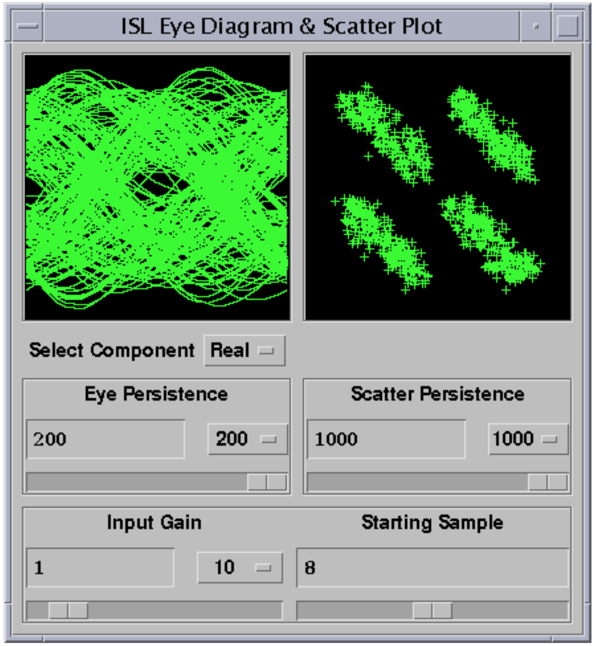


Sum of WV and Interferer signals at Eb/No=19.4 dB

WV Receiver Eye Diagrams and Constellation Plots Show Effect of Interference



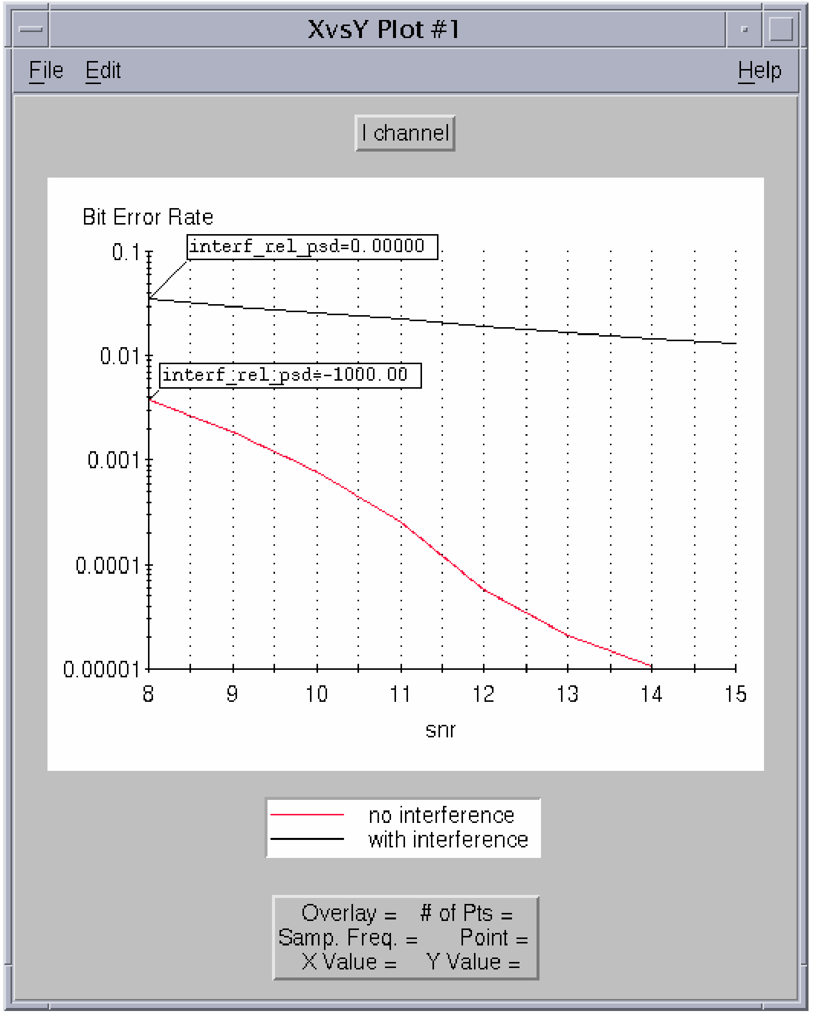
No Interference

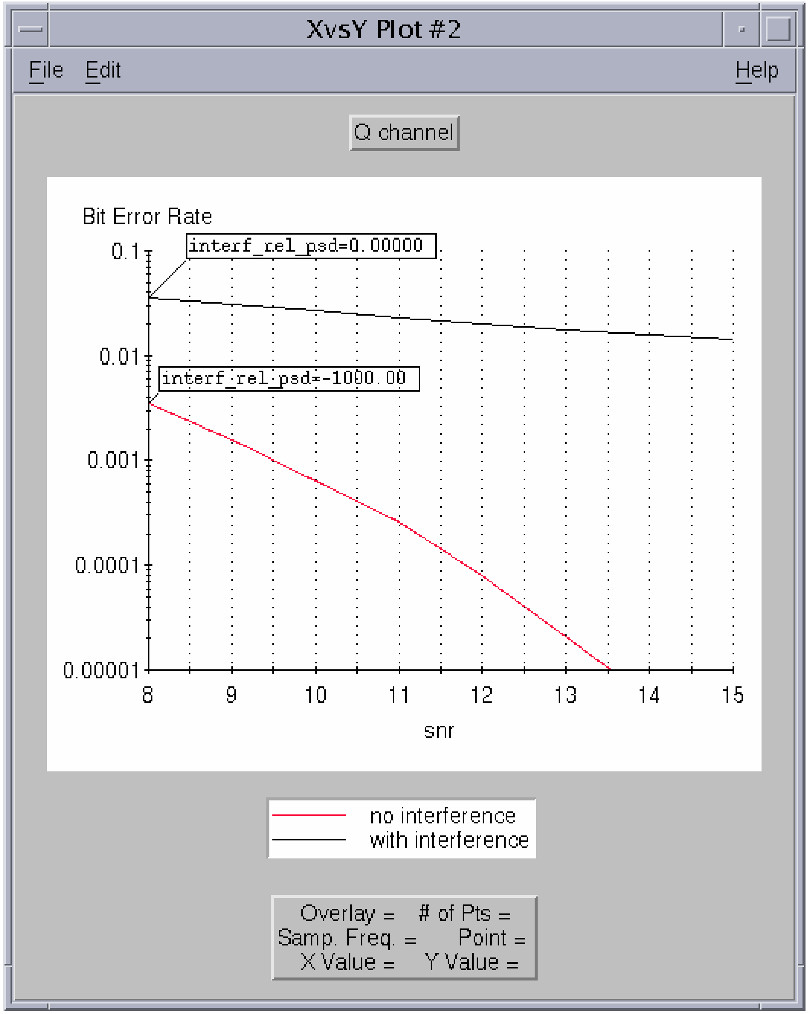


With Interference

Eb/No = 19.4 dB

BER vs. Eb/No Plots Show Impact to WV of Interferer





Future DG Missions Consider Ka Band Option

- Subsequent DG space missions will require increased data rates to the ground for image data
  - As spatial and spectral resolutions improve, more pixels per image must be downlinked
- X-band may be nearly exhausted in bits/Hz
  - Dual-pol, 8PSK (~1.0 Gbps) may be an option
    - EIRP, axial ratio requirements will be more severe than WV system
    - Feasibility may depend on WV system performance
- Available spectrum exists at Ka-band
  - 1.5 GHz of spectrum -> single-pol, QPSK systems feasible
- Ka-band flight transmitter hardware is not commercially available yet